Measurement of Low Energy Primary Cosmic Ray Protons on IMP-1 Satellite

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The first precise determination of the intensity and energy spectra of primary cosmic ray protons in the 15-75 MeV interval has been made with a three element energy vs. energy-loss telescope aboard the IMP-1 (Explorer XVIII) satellite. This spacecraft had an apogee of 193,000 km and only data obtained well beyond the effects of the earth's magnetosphere are considered. The measurements reported here cover the time interval 8 December 1963 to 6 May 1964 and are considered to be representative of the period just prior to solar minimum. The proton intensity in the range 15-75 MeV was observed to be 19 proton/m^2-sec-ster or approximately 1% of the total primary cosmic ray intensity and to exhibit a steeply falling energy spectrum toward lower energies, decreasing by a factor of 5 over this interval. One point for helium was obtained in the range 65-75 MeV/nuc.

The E vs dE/dx telescope (Figure 1a) provides a means of studying this low energy component in the presence of higher energy cosmic rays[1]. Because of the background and low flux in this energy interval, significant measurements cannot be obtained by balloon or rocket techniques but are dependent on satellite measurements. The principal of operation of the telescope is shown in Figure 1. For each particle which traverses the ΔE counter and stops in the E crystal (as defined by the plastic scintillator anticoincidence cup) measurements of ΔE and E - ΔE are made by 512 channel pulse height analyzers and transmitted over the satellite telemetry systems. As shown in Figure 1b, this provides a measure of mass, charge and energy resolution for Z = 1, 2 particles. The electron data is discussed in an accompanying paper. Saturation effects prevented the alpha particle data from being extended to lower energies. This does not affect the H or e data. Mass histograms have been obtained in the proton region for six energy intervals of about 10 MeV each by summing the data in 11 channels constructed parallel to and centered about the proton line of Figure 1b. These six energy intervals for H are shown in Figure 2. The clean resolution of the proton distribution at all energies is striking. The background correction (illustrated by the dashed line of Figure 2) has been applied using the experimental proton distribution obtained from the small solar cosmic ray event of 16 March 1964. The rigidity and energy spectra obtained from the mass histogram data of Figure 2 along with the single α point is shown in Figure 3.

To search for long term variations, the data were divided into two intervals covering the period 8 December 1963 - 14 March 1964 and 22 March 1964 - 6 May 1964. Except at the lowest energy point, the data are consistent with a change of less than 10% in the proton flux in the 15-75 MeV region between these two periods. The increase on the low energy point may be due to an increase in the galactic flux or, most probably, to the small solar proton event of 16 March 1964. We cannot rule out large short time variations since the long times required to obtain meaningful statistics preclude the possibility of observing variations occurring over a shorter time scale. Proton and helium data obtained at higher energies from the balloon data of Balasubrahmanyan and McDonald[2], and Fichtel et. al.[3] are shown for comparison. It is observed that at this period of the solar cycle just

[redacted]

prior to solar minimum there is a sharp decrease in both spectra toward lower energies that extends to the lowest observed energy.

The flux of deuterium could not be resolved from the background and an upper limit of 8% of the proton flux over the corresponding energy interval was placed on its abundance.

During the last solar minimum an arctic latitude survey by Meredith, et.al[4]. using a rocket borne single Geiger counter had indicated the cosmic ray intensity did not increase strongly at low energies. The ionization chamber data of Neher[5] at balloon altitude suggested a strong variation in the low energy range >100 MeV anti-correlated with solar activity.

The only previous satellite measurements in this region were made by Stone[6] in late 1961 on a polar orbiting satellite. This study was based on 12 counts in the energy interval 11-125 MeV. They were consistent with a flat energy spectrum and served to place an upper limit of about 1 proton/m^2-sec-MeV on the proton flux since an active anticoincidence device was not used. The data in Figure 3 show the highest energy point of the IMP data reported here is in general agreement with the lowest energy point obtained in the June 1963 balloon flight by Balasubrahmanyan and McDonald[2] and Fichtel[3], et. al. It is also consistent with the upper limit of $dJ/dE < .49$ protons/m^2-sec-MeV obtained on a high latitude flight of Brunstein in 1962[7] and with the lowest energy points obtained by Freier and Waddington[8] and Ornes and Webber[9] from 1963 balloon flights. Further confirmation of the splitting of the normalized low rigidity spectra is also obtained.

The proton and alpha spectra as observed in interplanetary space result from a superposition of three processes - initial acceleration, diffusion through the galaxy and solar modulation. To illustrate these processes assume

(1) Energy spectra at injection are of the form

$$\mu(E) = \frac{10^4}{w(1 + E)^{2.5}} \quad \text{protons}/M^3\text{-ster-BeV}$$

(2) Traversal of 2.5 gm/cm^2 of hydrogen before reaching the solar system; and

(3) The solar modulation is of the form

$$\frac{dj}{dE} = \frac{dj_o}{dE} \exp\left(- \frac{\text{const}}{w}\right)$$

where μ (E) is the density of cosmic rays with kinetic energy E, and dj/dE is the observed differential energy spectrum while dj_o/dE is the unmodulated or stellar spectrum and w is the particle velocity. Assumption (1) is based on an extrapolation to low energies of observations above 4 Bev[10]. The 2.5 gm/cm^2 of H is implied by the relative abundance of Li, Be, and B in the primary beam[11] and the solar modulation function is a diffusion model proposed by Parker[12]. In this model an equilibrium state is established between diffusion inward through irregular magnetic fields and removal by outward convection. The solar modulation effects have been obtained by normalizing at 200 MeV. These calculations are shown by the dotted curve of Figure 3b. While it can be concluded that either the injection spectra are steeper than a simple power law (as one might hypothesize from solar cosmic ray studies) or that the effects of solar modulation are not as strong at low energies (in agreement with the lack of significant long term time variations), the primary effect of these admittedly crude assumptions is to show that indeed the production of the observed steep proton energy spectrum is not unexpected on the basis of other cosmic ray observations. It is to be expected that further observations over the period of solar minimum coupled with low energy measurements of multiply charged primaries will permit more accurate determinations of the source spectra and the solar modulation mechanism.

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FIGURE CAPTIONS

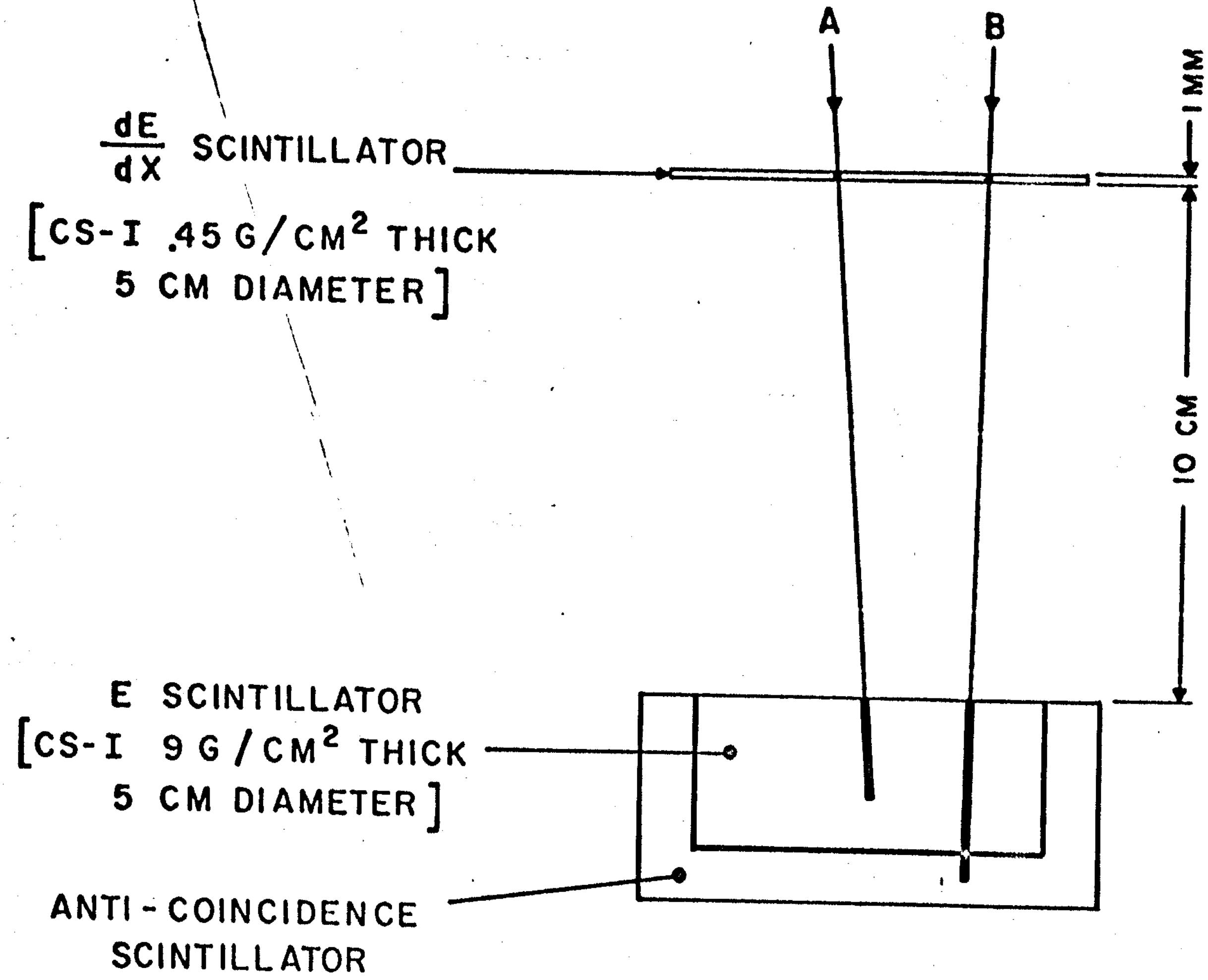
1(a) Schematic Drawing of E vs dE/dx Telescope. Particles which stop in the lower scintillator (A) are accepted for analysis while those which enter the anticoincidence cup (B) are rejected.

1(b) Mass and Energy Response of E $\left[\sim(E-\Delta E)\right]$ and dE/dx ($\sim\Delta E$) Telescope.

2 Mass Histogram for 6 Energy Intervals in Proton Region.

3(a) Cosmic Ray Proton Energy Spectra for Two Different Time Periods. The dotted line indicates an Empirical Fit to the Data of the form $10^{-3}\ E^{1.5}$.

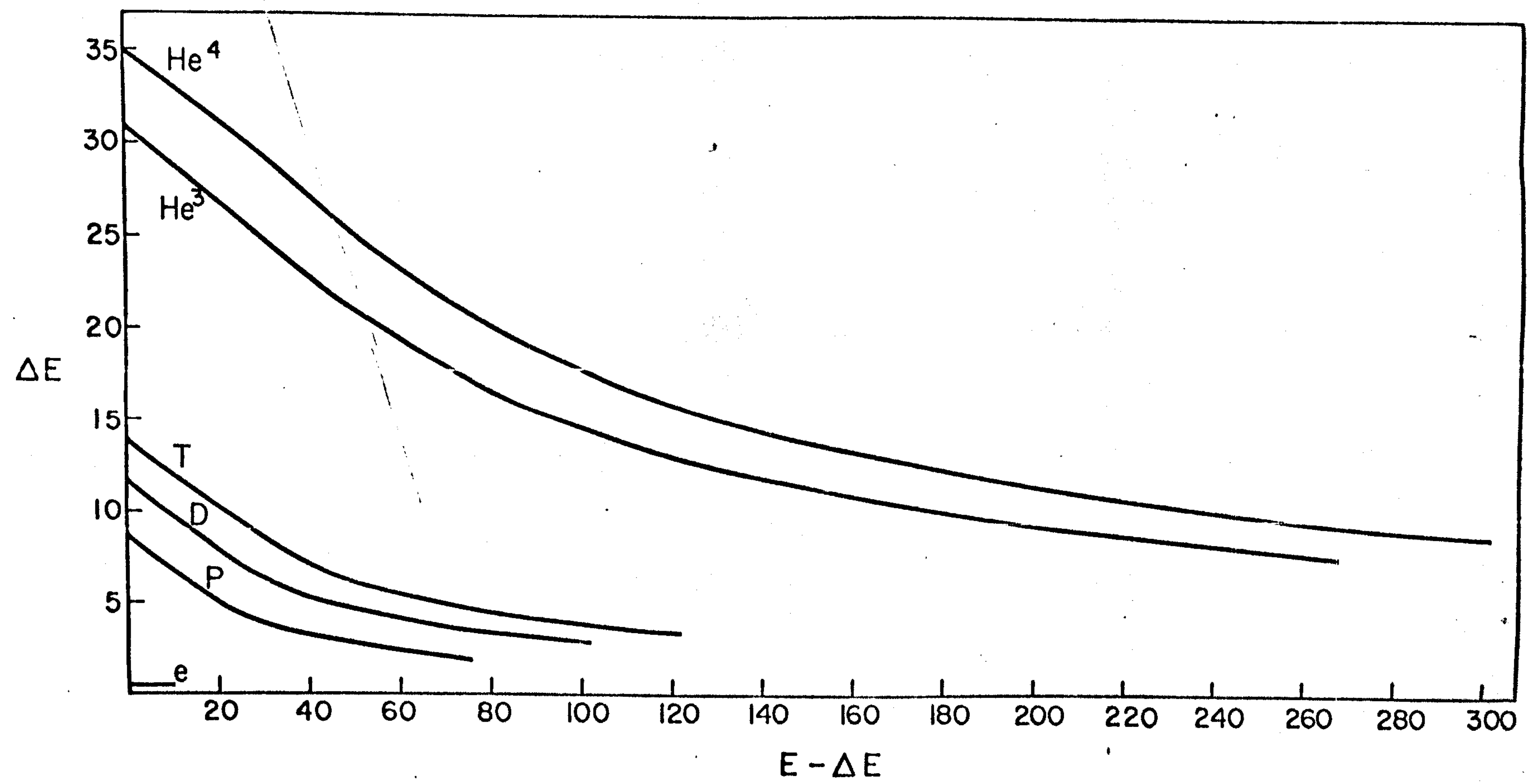
3(b) IMP Proton and α Rigidity Spectra. Shown for Comparison is the Balloon Data of Fichtel et.al.[3] and Balasubrahmanyan et.al.[2].



A
B
1 MM
10 CM
dE/dX SCINTILLATOR
[CS-I .45 G/CM² THICK
5 CM DIAMETER]
E SCINTILLATOR
[CS-I 9 G/CM² THICK
5 CM DIAMETER]
ANTI-COINCIDENCE
SCINTILLATOR

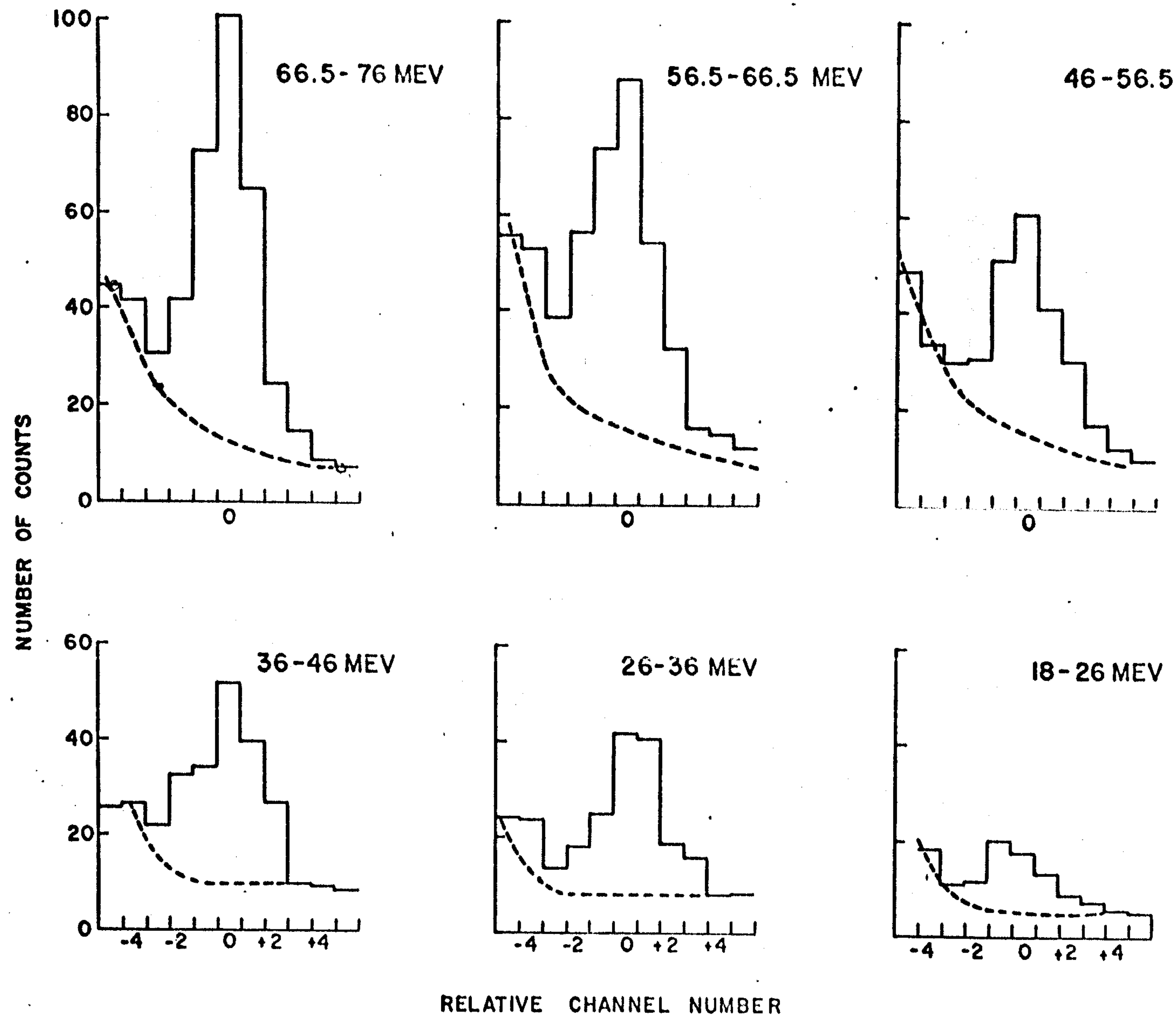
fig. 1

Fig 1(a)



He4
He3
T
D
P
e
35
30
25
20
15
10
5
ΔE
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
E - ΔE

Fig 1(a)



PROTON PULSE HEIGHT DISTRIBUTION

Fig 2

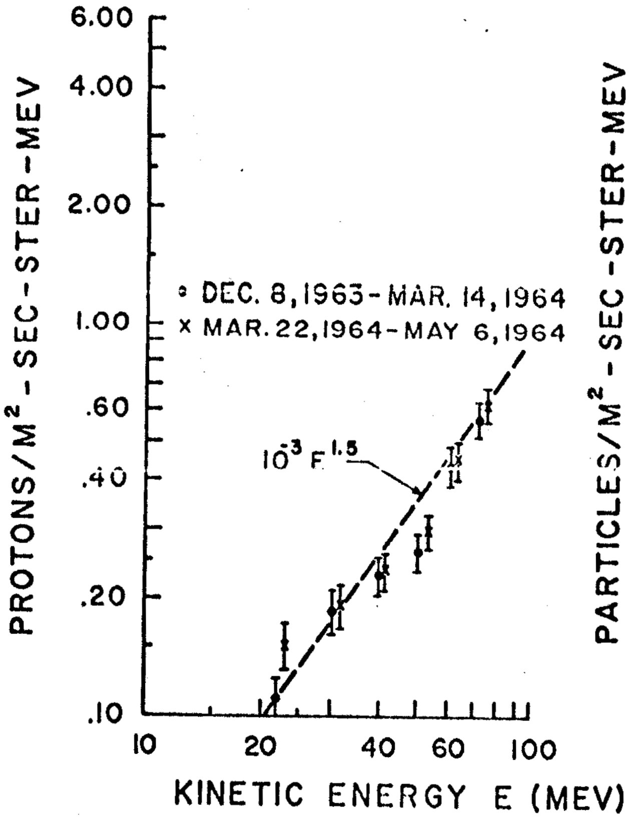


FIG. 3(a)

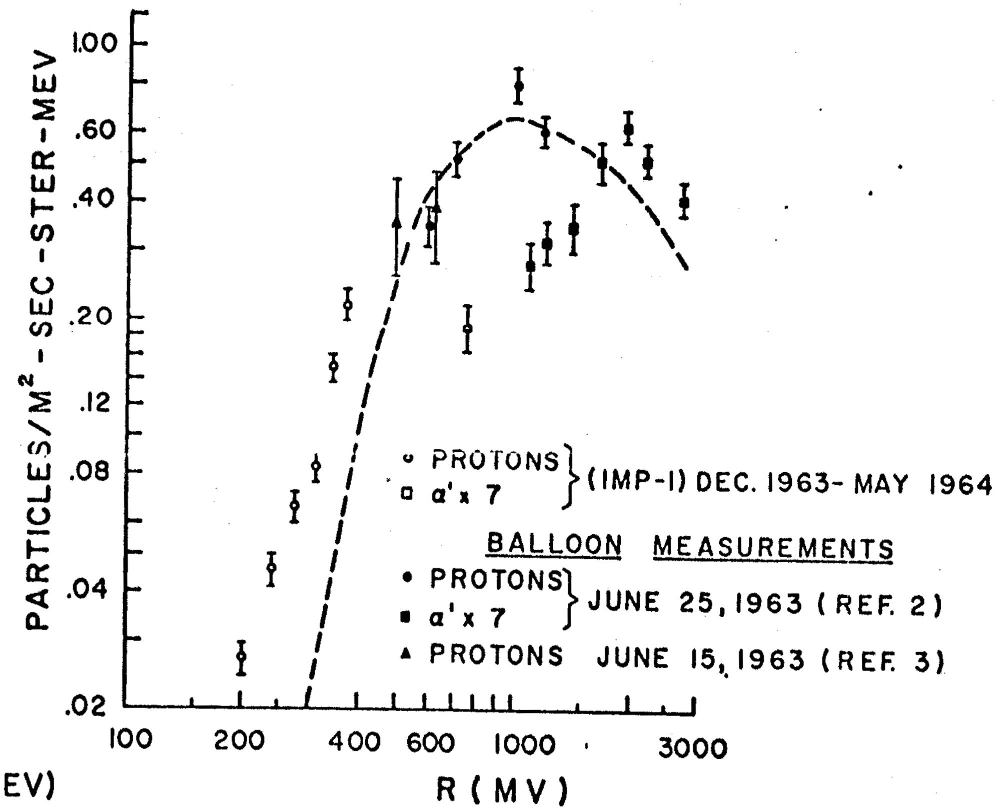


FIG. 3(b)

Fig 3